NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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GUST-LOAD AND AIRSPEED DATA FROM ONE TYPE OF FOUR-ENGINE AIRPLANE ON FIVE ROUTES FROM 1947 TO 1954

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SUMMARY

This paper presents the results of an analysis of approximately 100,000 hours of V-G data from one type of four-engine civil transport airplane to determine the magnitude and frequency of occurrence of the gust loads and gusts. The data were obtained during routine operations from 1947 to 1954 on five different routes. The normal accelerations for each of the five operations may be expected to exceed the value corresponding to the limit-gust-load-factor increment, on the average, twice (once positive and once negative) within the range of 5.0×10^6 to 22.3×10^6 flight miles. A derived gust velocity of 50 feet per second was exceeded twice within the range of 0.6×10^6 to 1.9×10^6 flight miles. The gust loads of the present operations were less than the loads experienced by other four-engine civil transports previously investigated, but the differences are not significant. The present data indicated only small differences due to seasonal effects and different operational utilization.

INTRODUCTION

Normal-acceleration and airspeed data obtained from flight recorders installed in airline aircraft are being evaluated by the National Advisory Committee for Aeronautics to determine the gust loads, gusts, and airspeeds during routine transport operations. Some results reported for past investigations (see refs. 1 to 3) have served as a means to extend general knowledge of gust loads. As a part of this continuing study, V-G data representing about 100,000 hours of operations have been collected from four-engine aircraft of one type. The records were from operations over five different domestic and foreign routes during the period from 1947 to 1954 and constitute the largest continuous sample obtained to date for a particular airplane.

This report presents the results of an evaluation of these records in terms of the frequency of occurrence of given values of normal

acceleration, airspeed, and derived gust velocity. Some comparisons of these results with those for recent operations of other four-engine civil transports are also presented.

SYMBOLS

a_n	normal acceleration, g units
$a_{n_{LLF}}$	normal acceleration corresponding to the design limit-gust-load-factor increment, g units
A	aspect ratio, b^2/S
b	wing span, ft
c	mean geometric chord, ft
g	acceleration due to gravity, ft/sec^2
K_g	gust factor (function of μ_g)
m	slope of wing lift curve per radian
n	design limit-gust-load factor
S	wing area, sq ft
U_{de}	derived gust velocity (see ref. 2, appendix A)
V	airspeed
V_{max}	maximum indicated airspeed, mph
V_B	design speed for maximum gust intensity, mph (ref. 4, p. 3)
V_C	design cruising speed, mph (ref. 4, p. 3)
V_D	design diving speed, mph (ref. 4, p. 3)
V_L	design level speed, mph (ref. 5, p. 4)
V_{NE}	never-exceed speed, mph (ref. 4, p. 36)
V_o	indicated airspeed at which maximum positive or negative acceleration occurs on a V-G record, mph

V_p most probable operating speed at which maximum acceleration occurs in a sample of V-G data, mph

W airplane weight, lb

k_v, k_o coefficients of skewness of distributions of V_{max} and V_o, respectively (ref. 2, appendix B)

σ_v, σ_o standard deviations of distributions of V_{max} and V_o, respectively (ref. 2, appendix B)

u location parameter of distribution of extreme values (ref. 6, p. 2)

α scale parameter of distribution of extreme values (ref. 6, p. 2)

ρ mass density of air, slugs/cu ft

ρ_o mass density of air at sea level, slugs/cu ft

μ_g airplane mass ratio, $\dfrac{2W}{\rho mgcS}$

Subscripts:

max maximum value of the variable

50 value of 50 feet per second for the derived gust velocity

A bar over a symbol indicates the mean value of the variable for a given set of observations.

APPARATUS AND SCOPE OF DATA

NACA V-G recorders (see ref. 7) were installed close to the center of gravity of each of 24 airplanes utilized for collecting the V-G records. Airplane characteristics pertinent to the evaluation of the records are:

Gross weight, W, lb	70,700
Wing area, S, sq ft	1,461
Mean geometric wing chord, c, ft	13.6
Aspect ratio, A	9.5
Lift-curve slope, m, per radian $\left(\text{computed from } \dfrac{6A}{A + 2}\right)$	4.96

Gust factor, K_g	0.711
Design limit-gust-load factor, n (computed according to ref. 5)	2.59
Design speed for maximum gust intensity, V_B, mph	166
Design cruising speed, V_C, mph	222
Design diving speed, V_D, mph	330
Design level speed, V_L, mph	250
Never-exceed speed, V_{NE}, mph	266

As in past analyses of V-G data, these values were obtained from the manufacturer's design data and the airplane operating manual or were computed as indicated in the table. The design of the present airplane was covered by earlier regulations which required the design limit-gust-load factor n to be computed at a design level speed V_L (ref. 5). The design limit-gust-load factor value of 2.59 shown in the above table is therefore based on the V_L value listed in the table. In order to compare these results with other data from airplanes of later design, the additional airspeeds (V_B, V_C, and V_D) which more nearly correspond to the present design requirements (see ref. 4) were calculated or assumed.

The scope of the present V-G data is summarized in table I for the different operations designated as A, B, C, D-I, and D-II. As table I shows, a smaller number of records was analyzed than was evaluated in each sample since, in accordance with past procedures (see, for example, ref. 2), only those records having reasonably constant record times should be used. Because of the limited number of records of operation B, however, all the records evaluated, except one questionable record, were analyzed so that the results obtained would be based on a reasonable sample size. Portions of the V-G data listed for operations D-I and D-II were previously analyzed and the results are reported in reference 8.

ANALYSIS AND RESULTS

The V-G records summarized in table I were evaluated in accordance with the methods of references 2 and 6. Briefly, the data read from each record were the maximum positive and negative accelerations $a_{n_{max}}$, their corresponding indicated airspeeds V_o, and the maximum airspeed V_{max}. In order to exclude accelerations due to impact shocks associated with landings and take-offs, the records were not read at speeds below 120 miles per hour. The accelerations and airspeeds are summarized in table II in the form of frequency distributions for each operation.

As a measure of severity of the turbulence associated with these V-G records, the maximum positive and negative derived gust velocities

$U_{de_{max}}$ were computed for each record by using the revised gust-load formula of reference 9:

$$U_{de_{max}} = \frac{2a_n W}{m\rho_o S V_o K_g} \tag{1}$$

where a_n and V_o are the accelerations and associated airspeeds from the records. For the computation of these gust velocities, an average operating weight of 85 percent gross weight was assumed, and the value of K_g used (obtained from fig. 2 of ref. 9) is based on μ_g for an assumed average operating altitude of 10,000 feet. The frequency distributions of the derived gust velocities computed for the present operations are also summarized in table II.

For convenience in comparing the acceleration, gust-velocity, and airspeed data of the operations, the theoretical probabilities of exceeding stated values of the variables were determined for the observed distributions of table II. The distribution of extreme values (see ref. 6) was applied to the acceleration and gust-velocity data, as detailed in reference 2, by use of the mean values $\bar{a}_{n_{max}}$ and $\bar{U}_{de_{max}}$, the location parameter μ, and the scale parameter α of the distributions. Pearson type-III distributions (see ref. 10) were calculated for the distributions of maximum airspeeds by using the mean value $\bar{V}_{max}$, the standard deviation σ, and the coefficient of skewness k of the distributions. The theoretical probabilities thus obtained were transformed into flight miles by use of an assumed average operating speed of $0.8V_L$, the average flight hours per record, and equation (3) of reference 2. Figures 1 to 3 present the resulting curves which represent the acceleration, gust-velocity, and maximum-airspeed results, respectively, in terms of the average flight miles to exceed stated levels of the relevant variable.

The pertinent results from figures 1 to 3 are summarized in table III as the average flight miles to exceed $a_{n_{LLF}}$, the value of acceleration that corresponds to the design limit-gust-load-factor increment, the derived-gust-velocity value $U_{de_{max}}$ of 50 feet per second, and the never-exceed speed V_{NE}. For additional information on the operating practices in rough air, the most probable speed V_p for experiencing maximum acceleration was derived by use of the relevant equation of reference 1 and the V_o data of table II. The V_p values are shown in table III for each operation.

In order to represent more completely the acceleration and gust-velocity data of the five operations, the maximum positive and negative

accelerations in 20-mph speed brackets were read from each record. The resulting frequency distributions of accelerations and airspeeds, shown in table IV, were used to derive gust-load and gust-velocity envelopes according to the procedures used in reference 2. The envelopes for 10^7 miles are shown in figures 4 and 5. The value of 10^7 miles was used for convenience in comparing the present data with previous results.

RELIABILITY OF RESULTS

The reliability of sample estimates obtained from V-G records depends on the number of observations used to obtain the estimates and may also be affected by instrumental errors and errors in reading the records. Instrumental and reading errors are believed to be random and to be small in the present data.

The reliability of the estimated maximum values of acceleration and gust velocity was determined through application of the method of reference 11 for determining confidence bands. These confidence bands yield the range within which, for the probability level of 95 percent used herein, the true value of the pertinent variable may be expected to lie. For the curves of figure 1 at the $a_{n_{LLF}}$ level the confidence bands had a maximum spread in average flight miles of 10:1. (At this level the spread of the $a_{n_{max}}$ values for the five operations is only about 15 percent.) For figure 2 at the 50-foot-per-second level of $U_{de_{max}}$ the confidence bands had a maximum spread of 6:1 (which corresponds to a spread in $U_{de_{max}}$ of about 18 percent). Accordingly, where the present results are compared with those from past operations, any differences between the estimated values of $a_{n_{LLF}}$ or $U_{de_{50}}$ are considered significant if the values of average flight miles to exceed given values of these variables differ by more than a factor of 10:1 or 6:1, respectively.

The effect of dynamic response on the accelerations measured at the center of gravity in the present investigation is unknown and is not accounted for in the results shown. This effect should have no bearing on comparisons between the several operations involved in the present investigation since only one type of airplane is represented. Where results from other investigations are compared with the present results, it is assumed that dynamic response would not appreciably influence the results shown since the flexibility of the airplanes considered was felt to be comparable.

No adequate method is available for easily determining the statistical reliability of the estimates of maximum airspeeds. For the results

shown in figure 3, the estimates of the flight miles to exceed V_{NE} are used only as an indication of the order of magnitude.

DISCUSSION

Accelerations Experienced

The normal accelerations for each of the five operations (see fig. 1 and table III) may be expected to exceed the value $a_{n_{LLF}}$, on the average, twice (once positive and once negative) within the range of 5.0×10^6 to 22.3×10^6 flight miles. These differences in flight miles are not significant on the basis of the 10:1 criterion cited previously. At 10^7 flight miles (see fig. 1), the maximum accelerations for the different operations had a spread of only about 0.2g. On the basis of these results, it may be concluded that the loads experienced were about the same for the five operations compared.

A comparison of the present accelerations with those experienced in recent operations of other four-engine civil transports is given in the following table:

Group of operations	Period	Average flight miles to exceed $a_{n_{LLF}}$ twice
Present (range of five cases)	1947 to 1954	5.0×10^6 to 22.3×10^6
Reference 1 (two different routes)	1941 to 1945	4.9×10^6 and 7.5×10^6
Reference 2 (range of three routes)	1949 to 1953	0.9×10^6 to 1.4×10^6
Reference 3 (Eastern U. S. route)	1947 to 1950	1.1×10^6

On the basis of the 10:1 criterion for significance, the comparison in this table indicates that in most cases only minor differences occurred between the accelerations of the present airplanes and the accelerations experienced by other four-engine transports during recent operations.

Although these results indicate that the gust loads of the present operations were less than the loads experienced by the other four-engine transports, the differences are of small importance.

Roughly half of the V-G records obtained from operation A were taken during troop-carrier service whereas the rest of these records were taken during cargo operations. A separate analysis was made of the acceleration data from those records to determine whether the operational differences influenced the loads. Although the results indicated that the accelerations for the troop-carrier operations were somewhat less severe than those for the cargo operations, the differences noted are not considered significant.

A breakdown of the present acceleration data according to season (the B and D-I results excepted because the data were not suited to seasonal analysis) is given in the following table:

Operation	Average flight miles to exceed $a_{n_{LLF}}$ twice in –	
	Summer	Winter
A	3.6×10^6	5.9×10^6
B	----------	----------
C	8.1	16.2
D-I	----------	----------
D-II	17.0	29.6

Inasmuch as most differences in this table between summer and winter operations are about 2:1, the effect of season in each case is unimportant. Owing to the fact that these results show a consistent trend, however, the operating conditions in the winter might be considered as less severe than those in the summer.

Gusts Encountered

The gusts encountered in each of the present operations (see table III) exceeded a derived gust velocity $U_{de_{max}}$ of 50 feet per second, on the average, twice within the range of 0.6×10^6 to

1.9×10^6 flight miles. This relatively small variation in the flight miles indicates that the level of turbulence in each of these operations was about the same. This indication of the turbulence intensity is reflected in the gust loads cited previously.

A comparison of the gusts encountered in the present operations with those encountered in the operations of other civil transports is given in the following table:

Group of operations	Period	Average flight miles to exceed $U_{de_{50}}$ twice
Present (range of five cases)	1947 to 1954	0.6×10^6 to 1.9×10^6
Reference 1 (two different routes)	1941 to 1945	0.4×10^6 and 0.5×10^6
Reference 2 (range of three routes)	1949 to 1953	0.4×10^6 to 0.7×10^6
Reference 3 (Eastern U. S. route)	1947 to 1950	0.7×10^6

This table indicates that, on the basis of the 6:1 criterion discussed previously, the gusts encountered in the present operations and those encountered in each of the other operations are not significantly different. The relative level of atmospheric turbulence encountered was about the same for all these operations.

Operating Airspeeds

An inspection of the speeds V_p at which maximum accelerations occurred in these operations (see table III) indicates a spread of only about 10 mph and an average value of about 178 mph. This average speed closely approximates $0.8V_C$ (based on V_C equal to 222 mph). An inspection of references 1 to 3 indicated that the average value of V_p for the operations of the other four-engine transports also approximated $0.8V_C$. Any differences in V_p therefore had small effect on the gust

loads of the present operations and those of the other operations previously compared.

Table III indicates that the never-exceed speed V_{NE} (taken as 266 mph herein) would be exceeded once within the range of 1.5×10^6 to 20×10^6 flight miles in each of the five operations. An examination of table II(c) shows that maximum airspeeds in excess of 266 mph occurred in only eight records. During the times these records were taken, the high speeds were attained in low turbulence; accordingly, it is felt that the operating speed practices were generally conservative.

Gust-Load Envelopes

An inspection of figure 4 shows that the calculated gust-load envelopes for all five operations fall within a design diagram which is based on the accelerations computed through the use of the design requirements of the Civil Aeronautics Administration (see ref. 4) and on the airspeeds V_B, V_L (as previously mentioned, V_L is the actual design value for this airplane and is used rather than V_C), and V_D for this airplane. A direct comparison of these calculated envelopes with the design diagram is possible as a result of scaling the envelope accelerations from 85 percent gross weight (this weight was assumed as the average airplane weight during the times the accelerations were measured in these operations) to the airplane gross weight. Figure 4 indicates an appreciable increase in the margin of safety at speeds above the design level speed V_L.

Gust-Velocity Envelopes

The gust-velocity envelopes derived for the five present operations (see fig. 5) agree well with the overall range in similar envelopes calculated from the data of references 2 and 3. Certain factors, such as differences in weights and operating altitudes in turbulence and differences in dynamic response, may have influenced these results. Speed differences between types of airplanes are accounted for, however, by plotting the airspeeds according to the relation V/V_C. The overall ranges in levels of turbulence encountered appear from figure 5 to have been roughly the same for the present and the past operations.

CONCLUDING REMARKS

The results of an analysis of V-G data from one type of four-engine civil transport airplane indicated that the normal accelerations differed

by approximately 15 percent and the derived gust velocities by about 18 percent for the five operations investigated. The gust loads of the present operations were less than the loads experienced by other four-engine civil transports previously investigated, but the differences are not significant. The present data indicated only small differences due to seasonal effects and different operational utilization.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 7, 1954.

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TABLE I

SCOPE OF V-G DATA FOR OPERATIONS FROM 1947 TO 1954

Operation	Routes flown	Dates of operation	Number of airplanes supplying records	Records evaluated		Records analyzed				
				Number	Total hours	Number	Total hours	Range of record hours	Average hours per record	Indicated flight miles
A	New York-Los Angeles-Seattle-Tokyo	Aug. 1950 to Aug. 1953	4	70	13,165	42	7,057	100 to 300	168	1.41×10^6
B	Chicago-New Orleans-Caracas	June 1948 to Nov. 1950	3	21	7,647	20	7,305	88 to 584	365	1.46×10^6
C	New York-Seattle-Honolulu-Tokyo-Manila	May 1949 to June 1953	3	65	25,947	40	12,780	200 to 600	320	2.56×10^6
D-I	Miami-Caribbean-South America	Nov. 1947 to June 1950	4	64	17,882	57	15,327	180 to 320	269	3.07×10^6
D-II	San Francisco-Australia-Orient	Mar. 1947 to Jan. 1950	10	148	34,552	117	27,288	180 to 320	233	5.46×10^6

TABLE II

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS FOR DATA SAMPLES ANALYZED

(a) Normal accelerations, $a_{n_{max}}$

Normal acceleration, $\pm a_{n_{max}}$, g units	Number of observations for operation -				
	A	B	C	D-I	D-II
0.2 to 0.3	--	--	--	--	1
.3 to .4	1	--	2	--	2
.4 to .5	3	--	2	1	16
.5 to .6	9	1	6	4	28
.6 to .7	9	2	12	6	37
.7 to .8	14	8	18	23	47
.8 to .9	20	7	12	16	51
.9 to 1.0	11	10	11	24	25
1.0 to 1.1	7	5	9	15	15
1.1 to 1.2	6	5	2	11	11
1.2 to 1.3	3	0	6	9	1
1.3 to 1.4	1	0	--	4	--
1.4 to 1.5	--	1	--	1	--
1.5 to 1.6	--	0	--	--	--
1.6 to 1.7	--	0	--	--	--
1.7 to 1.8	--	0	--	--	--
1.8 to 1.9	--	1	--	--	--
Total	84	40	80	114	234
$\bar{a}_{n_{max}}$, g units	0.83	0.94	0.83	0.94	0.77
u	0.74	0.84	0.73	0.84	0.68
α	6.10	5.60	6.06	6.20	6.80

TABLE II - Continued

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS

FOR DATA SAMPLES ANALYZED

(b) Airspeeds, V_o, for $a_{n_{max}}$

Airspeed, V_o, mph	Number of observations for operation -				
	A	B	C	D-I	D-II
120 to 130	1	2	8	5	6
130 to 140	1	4	5	6	12
140 to 150	5	2	4	5	14
150 to 160	5	5	6	5	14
160 to 170	9	4	16	13	51
170 to 180	24	4	9	19	51
180 to 190	23	9	14	22	57
190 to 200	9	6	6	14	14
200 to 210	3	2	9	13	10
210 to 220	3	1	2	3	4
220 to 230	1	1	1	5	1
230 to 240	--	--	--	4	--
Total	84	40	80	114	234
$\bar{V}_o$, mph	177.9	172.5	170.8	180.5	172.3
σ_o	17.82	24.80	25.43	26.09	19.05
k_o	-0.23	-0.20	-0.20	-0.17	-0.34
V_p, mph	180.0	174.9	173.3	182.7	175.5

TABLE II - Continued

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS

FOR DATA SAMPLES ANALYZED

(c) Maximum airspeeds, V_{max}

Airspeed, V_{max}, mph	Number of observations for operation -				
	A	B	C	D-I	D-II
205 to 210	--	--	1	--	--
210 to 215	--	1	1	--	--
215 to 220	--	0	1	--	--
220 to 225	6	0	3	--	8
225 to 230	6	3	6	--	21
230 to 235	6	1	6	--	37
235 to 240	7	2	7	4	26
240 to 245	7	3	7	15	14
245 to 250	3	3	5	16	8
250 to 255	4	3	1	8	0
255 to 260	0	4	0	8	0
260 to 265	2	--	0	3	1
265 to 270	0	--	1	3	1
270 to 275	1	--	0	--	0
275 to 280	--	--	1	--	1
Total	42	20	40	57	117
$\bar{V}_{max}$, mph	238.2	234.0	236.5	249.4	235.2
σ_V	11.85	12.25	12.45	7.75	8.51
k_V	0.74	-0.71	0.61	0.64	1.72

TABLE II - Concluded

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS

FOR DATA SAMPLES ANALYZED

(d) Derived gust velocities, $U_{de_{max}}$

Gust velocity, $\pm U_{de_{max}}$, fps	Number of observations for operation -				
	A	B	C	D-I	D-II
12 to 16	--	--	1	--	3
16 to 20	3	--	5	1	18
20 to 24	6	4	4	3	20
24 to 28	16	1	11	13	43
28 to 32	17	2	16	15	43
32 to 36	20	10	12	17	44
36 to 40	9	10	8	20	33
40 to 44	7	4	9	15	19
44 to 48	5	3	6	13	9
48 to 52	0	1	4	12	1
52 to 56	1	3	2	3	0
56 to 60	--	0	0	2	1
60 to 64	--	1	1	--	--
64 to 68	--	0	1	--	--
68 to 72	--	1	--	--	--
Total	84	40	80	114	234
$\bar{U}_{de_{max}}$, fps	32.28	38.60	34.50	37.85	31.13
u	29.02	33.91	29.87	33.91	27.63
α	0.18	0.12	0.13	0.15	0.17

TABLE III

COMPARISON OF LOADS, GUSTS, AND AIRSPEEDS

FOR THE PRESENT OPERATIONS

Operation	V_p, mph	Average flight miles to exceed -		
		$a_{n_{LLF}}$ twice	$U_{de_{max}}$ of 50 fps twice	V_{NE} once
A	180	6.2×10^6	1.4×10^6	1.5×10^6
B	175	5.0	.6	20.0
C	173	11.6	.8	3.3
D-I	183	5.5	.6	1.8
D-II	176	22.3	1.9	5.7

TABLE IV

FREQUENCY DISTRIBUTIONS OF ACCELERATIONS BY AIRSPEED BRACKETS

(a) Operation A

Acceleration, $a_{n_{max}}$, g units	Number of observations for airspeed, mph, of -											
	140 to 160		160 to 180		180 to 200		200 to 220		220 to 240		240 to 260	
	+	-	+	-	+	-	+	-	+	-	+	-
0 to 0.1	--	--	--	--	--	--	--	--	--	1	--	1
.1 to .2	--	--	--	--	--	--	2	4	8	10	5	5
.2 to .3	--	--	--	--	2	2	4	4	9	7	4	1
.3 to .4	3	7	1	5	0	2	8	6	8	16	2	3
.4 to .5	13	4	1	5	2	6	8	5	8	1	1	1
.5 to .6	10	15	7	5	9	2	8	7	4	2	1	2
.6 to .7	7	4	7	8	6	5	5	6	1	1	--	--
.7 to .8	6	5	12	4	9	8	3	3	1	1	--	--
.8 to .9	1	6	9	6	8	8	1	2	1	2	--	--
.9 to 1.0	0	1	2	6	2	6	0	2	0	--	--	--
1.0 to 1.1	1	--	2	2	3	0	1	2	0	--	--	--
1.1 to 1.2	0	--	1	1	1	2	0	1	1	--	--	--
1.2 to 1.3	1	--	--	--	--	1	1	--	--	--	--	--
1.3 to 1.4	--	--	--	--	--	--	1	--	--	--	--	--
Total	42	42	42	42	42	42	42	42	41	41	13	13
$\bar{a}_{n_{max}}$, g units	0.59	0.59	0.74	0.69	0.70	0.72	0.53	0.54	0.38	0.33	0.27	0.28
u	0.51	0.52	0.66	0.59	0.69	0.62	0.41	0.43	0.28	0.25	0.21	0.21
α	7.09	7.58	7.81	5.83	6.33	5.38	5.00	4.90	6.14	6.90	10.75	7.81

TABLE IV - Continued

FREQUENCY DISTRIBUTIONS OF ACCELERATIONS BY AIRSPEED BRACKETS

(d) Operation D-I

Acceleration, $a_{n_{max}}$, g units	Number of observations for airspeed, mph, of -											
	140 to 160		160 to 180		180 to 200		200 to 220		220 to 240		240 to 260	
	+	-	+	-	+	-	+	-	+	-	+	-
0 to 0.1	--	--	--	--	--	--	--	--	--	--	4	3
.1 to .2	--	--	--	--	--	--	--	--	--	2	4	16
.2 to .3	--	--	--	--	--	--	--	1	3	5	11	14
.3 to .4	2	1	--	1	--	2	1	3	5	8	13	12
.4 to .5	7	7	2	4	3	1	9	9	12	13	14	2
.5 to .6	13	17	6	5	5	8	6	11	14	15	5	3
.6 to .7	13	8	8	16	10	6	10	13	10	4	0	1
.7 to .8	13	8	9	9	9	17	10	10	6	6	1	0
.8 to .9	5	7	15	8	10	9	6	3	3	2	--	1
.9 to 1.0	3	5	6	3	9	3	9	4	2	0	--	--
1.0 to 1.1	0	1	3	5	6	6	1	1	2	2	--	--
1.1 to 1.2	1	2	3	3	2	2	2	1	--	--	--	--
1.2 to 1.3	--	1	4	1	1	1	3	0	--	--	--	--
1.3 to 1.4	--	--	1	1	2	2	--	0	--	--	--	--
1.4 to 1.5	--	--	--	1	--	--	--	1	--	--	--	--
Total	57	57	57	57	57	57	57	57	57	57	52	52
$\bar{a}_{n_{max}}$, g units	0.66	0.69	0.83	0.78	0.82	0.79	0.75	0.66	0.58	0.52	0.34	0.25
u	0.59	0.60	0.74	0.70	0.73	0.70	0.65	0.57	0.50	0.43	0.28	0.18
α	8.00	6.37	5.96	6.90	6.00	5.82	5.65	6.33	6.85	6.62	8.70	8.20

TABLE IV

FREQUENCY DISTRIBUTIONS OF ACCELERATIONS BY AIRSPEED BRACKETS

(a) Operation A

Acceleration, $a_{n_{max}}$, g units	Number of observations for airspeed, mph, of -											
	140 to 160		160 to 180		180 to 200		200 to 220		220 to 240		240 to 260	
	+	-	+	-	+	-	+	-	+	-	+	-
0 to 0.1	--	--	--	--	--	--	--	--	--	1	--	1
.1 to .2	--	--	--	--	--	--	2	4	8	10	5	5
.2 to .3	--	--	--	--	2	2	4	4	9	7	4	1
.3 to .4	3	7	1	5	0	2	8	6	8	16	2	3
.4 to .5	13	4	1	5	2	6	8	5	8	1	1	1
.5 to .6	10	15	7	5	9	2	8	7	4	2	1	2
.6 to .7	7	4	7	8	6	5	5	6	1	1	--	--
.7 to .8	6	5	12	4	9	8	3	3	1	1	--	--
.8 to .9	1	6	9	6	8	8	1	2	1	2	--	--
.9 to 1.0	0	1	2	6	2	6	0	2	0	--	--	--
1.0 to 1.1	1	--	2	2	3	0	1	2	0	--	--	--
1.1 to 1.2	0	--	1	1	1	2	0	1	1	--	--	--
1.2 to 1.3	1	--	--	--	--	1	1	--	--	--	--	--
1.3 to 1.4	--	--	--	--	--	--	1	--	--	--	--	--
Total	42	42	42	42	42	42	42	42	41	41	13	13
$\bar{a}_{n_{max}}$, g units	0.59	0.59	0.74	0.69	0.70	0.72	0.53	0.54	0.38	0.33	0.27	0.28
u	0.51	0.52	0.66	0.59	0.69	0.62	0.41	0.43	0.28	0.25	0.21	0.21
α	7.09	7.58	7.81	5.83	6.33	5.38	5.00	4.90	6.14	6.90	10.75	7.81

TABLE IV - Continued

FREQUENCY DISTRIBUTIONS OF ACCELERATIONS BY AIRSPEED BRACKETS

(b) Operation B

Acceleration, $a_{n_{max}}$, g units	Number of observations for airspeed, mph, of -											
	140 to 160		160 to 180		180 to 200		200 to 220		220 to 240		240 to 260	
	+	-	+	-	+	-	+	-	+	-	+	-
0 to 0.1	--	--	--	--	--	--	--	--	--	--	--	1
.1 to .2	--	--	--	--	--	--	--	--	--	--	6	7
.2 to .3	--	--	--	--	--	--	--	--	--	4	2	3
.3 to .4	--	--	--	--	--	--	--	1	5	3	0	1
.4 to .5	2	2	--	--	--	3	1	1	4	3	5	0
.5 to .6	4	4	--	3	1	3	4	7	3	4	--	1
.6 to .7	4	3	4	5	3	2	9	6	3	3	--	--
.7 to .8	4	5	6	4	8	2	4	3	2	1	--	--
.8 to .9	2	1	5	5	4	3	1	1	2	0	--	--
.9 to 1.0	3	3	3	1	3	3	1	0	--	0	--	--
1.0 to 1.1	0	1	1	1	1	1	--	0	--	0	--	--
1.1 to 1.2	1	1	1	0	--	3	--	0	--	1	--	--
1.2 to 1.3	--	--	--	1	--	--	--	0	--	--	--	--
1.3 to 1.4	--	--	--	--	--	--	--	0	--	--	--	--
1.4 to 1.5	--	--	--	--	--	--	--	0	--	--	--	--
1.5 to 1.6	--	--	--	--	--	--	--	0	--	--	--	--
1.6 to 1.7	--	--	--	--	--	--	--	0	--	--	--	--
1.7 to 1.8	--	--	--	--	--	--	--	0	--	--	--	--
1.8 to 1.9	--	--	--	--	--	--	--	1	--	--	--	--
Total	20	20	20	20	20	20	20	20	19	19	13	13
$\bar{a}_{n_{max}}$, g units	0.72	0.74	0.82	0.77	0.79	0.79	0.67	0.68	0.55	0.50	0.28	0.21
u	0.65	0.65	0.76	0.69	0.64	0.68	0.61	0.54	0.47	0.40	0.22	0.16
α	6.85	6.49	9.26	7.25	10.42	5.32	11.23	4.30	7.46	5.78	9.00	10.20

TABLE IV - Continued

FREQUENCY DISTRIBUTIONS OF ACCELERATIONS BY AIRSPEED BRACKETS

(c) Operation C

Acceleration, $a_{n_{max}}$, g units	Number of observations for airspeed, mph, of -											
	140 to 160		160 to 180		180 to 200		200 to 220		220 to 240		240 to 260	
	+	-	+	-	+	-	+	-	+	-	+	-
0 to 0.1	--	--	--	--	--	--	--	1	3	2	--	1
.1 to .2	--	--	--	--	--	--	1	1	7	10	6	4
.2 to .3	--	1	1	--	2	2	6	4	11	6	4	5
.3 to .4	2	4	1	2	1	2	4	6	3	8	3	2
.4 to .5	8	5	6	8	6	9	7	7	5	4	--	1
.5 to .6	9	11	6	6	16	10	12	7	3	3	--	--
.6 to .7	7	3	6	12	3	7	5	6	2	1	--	--
.7 to .8	7	11	9	3	5	4	1	5	1	1	--	--
.8 to .9	3	3	6	5	3	1	2	1	--	--	--	--
.9 to 1.0	3	2	1	2	2	3	1	1	--	--	--	--
1.0 to 1.1	1	--	2	1	2	0	1	0	--	--	--	--
1.1 to 1.2	--	--	1	0	--	0	--	0	--	--	--	--
1.2 to 1.3	--	--	1	1	--	2	--	1	--	--	--	--
Total	40	40	40	40	40	40	40	40	35	35	13	13
$\bar{a}_{n_{max}}$, g units	0.64	0.62	0.70	0.65	0.62	0.61	0.51	0.53	0.31	0.31	0.23	0.24
u	0.56	0.54	0.60	0.56	0.53	0.51	0.42	0.42	0.23	0.23	0.18	0.19
α	7.30	7.35	5.95	6.54	6.67	5.72	6.40	5.58	7.04	7.57	13.11	12.00

TABLE IV - Continued

FREQUENCY DISTRIBUTIONS OF ACCELERATIONS BY AIRSPEED BRACKETS

(d) Operation D-I

Acceleration, $a_{n_{max}}$, g units	Number of observations for airspeed, mph, of -											
	140 to 160		160 to 180		180 to 200		200 to 220		220 to 240		240 to 260	
	+	-	+	-	+	-	+	-	+	-	+	-
0 to 0.1	--	--	--	--	--	--	--	--	--	--	4	3
.1 to .2	--	--	--	--	--	--	--	--	--	2	4	16
.2 to .3	--	--	--	--	--	--	--	1	3	5	11	14
.3 to .4	2	1	--	1	--	2	1	3	5	8	13	12
.4 to .5	7	7	2	4	3	1	9	9	12	13	14	2
.5 to .6	13	17	6	5	5	8	6	11	14	15	5	3
.6 to .7	13	8	8	16	10	6	10	13	10	4	0	1
.7 to .8	13	8	9	9	9	17	10	10	6	6	1	0
.8 to .9	5	7	15	8	10	9	6	3	3	2	--	1
.9 to 1.0	3	5	6	3	9	3	9	4	2	0	--	--
1.0 to 1.1	0	1	3	5	6	6	1	1	2	2	--	--
1.1 to 1.2	1	2	3	3	2	2	2	1	--	--	--	--
1.2 to 1.3	--	1	4	1	1	1	3	0	--	--	--	--
1.3 to 1.4	--	--	1	1	2	2	--	0	--	--	--	--
1.4 to 1.5	--	--	--	1	--	--	--	1	--	--	--	--
Total	57	57	57	57	57	57	57	57	57	57	52	52
$\bar{a}_{n_{max}}$, g units	0.66	0.69	0.83	0.78	0.82	0.79	0.75	0.66	0.58	0.52	0.34	0.25
u	0.59	0.60	0.74	0.70	0.73	0.70	0.65	0.57	0.50	0.43	0.28	0.18
α	8.00	6.37	5.96	6.90	6.00	5.82	5.65	6.33	6.85	6.62	8.70	8.20

TABLE IV - Concluded

FREQUENCY DISTRIBUTIONS OF ACCELERATIONS BY AIRSPEED BRACKETS

(e) Operation D-II

Acceleration, $a_{n_{max}}$, g units	Number of observations for airspeed, mph, of -											
	140 to 160		160 to 180		180 to 200		200 to 220		220 to 240		240 to 260	
	+	-	+	-	+	-	+	-	+	-	+	-
0 to 0.1	--	--	--	--	--	--	1	2	10	11	7	7
.1 to .2	--	--	--	--	--	3	5	6	28	28	7	6
.2 to .3	--	5	--	2	1	4	20	21	38	33	3	5
.3 to .4	10	14	6	7	6	13	22	21	26	18	3	1
.4 to .5	27	29	10	13	14	16	26	22	6	8	--	0
.5 to .6	19	20	16	27	25	18	20	16	4	9	--	0
.6 to .7	35	24	23	26	22	28	13	13	1	5	--	1
.7 to .8	13	14	17	23	22	16	8	10	1	1	--	--
.8 to .9	7	6	25	8	16	11	0	4	0	0	--	--
.9 to 1.0	5	5	11	6	4	3	2	1	1	2	--	--
1.0 to 1.1	1	--	3	5	3	3	--	1	--	--	--	--
1.1 to 1.2	--	--	5	--	4	2	--	--	--	--	--	--
1.2 to 1.3	--	--	1	--	--	--	--	--	--	--	--	--
Total	117	117	117	117	117	117	117	117	115	115	20	20
$\bar{a}_{n_{max}}$, g units	0.61	0.54	0.73	0.65	0.67	0.61	0.45	0.46	0.27	0.29	0.16	0.18
u	0.54	0.49	0.64	0.57	0.59	0.51	0.37	0.37	0.20	0.21	0.11	0.11
α	8.13	7.52	6.37	7.25	6.80	6.17	7.35	6.37	8.85	6.99	12.21	9.09

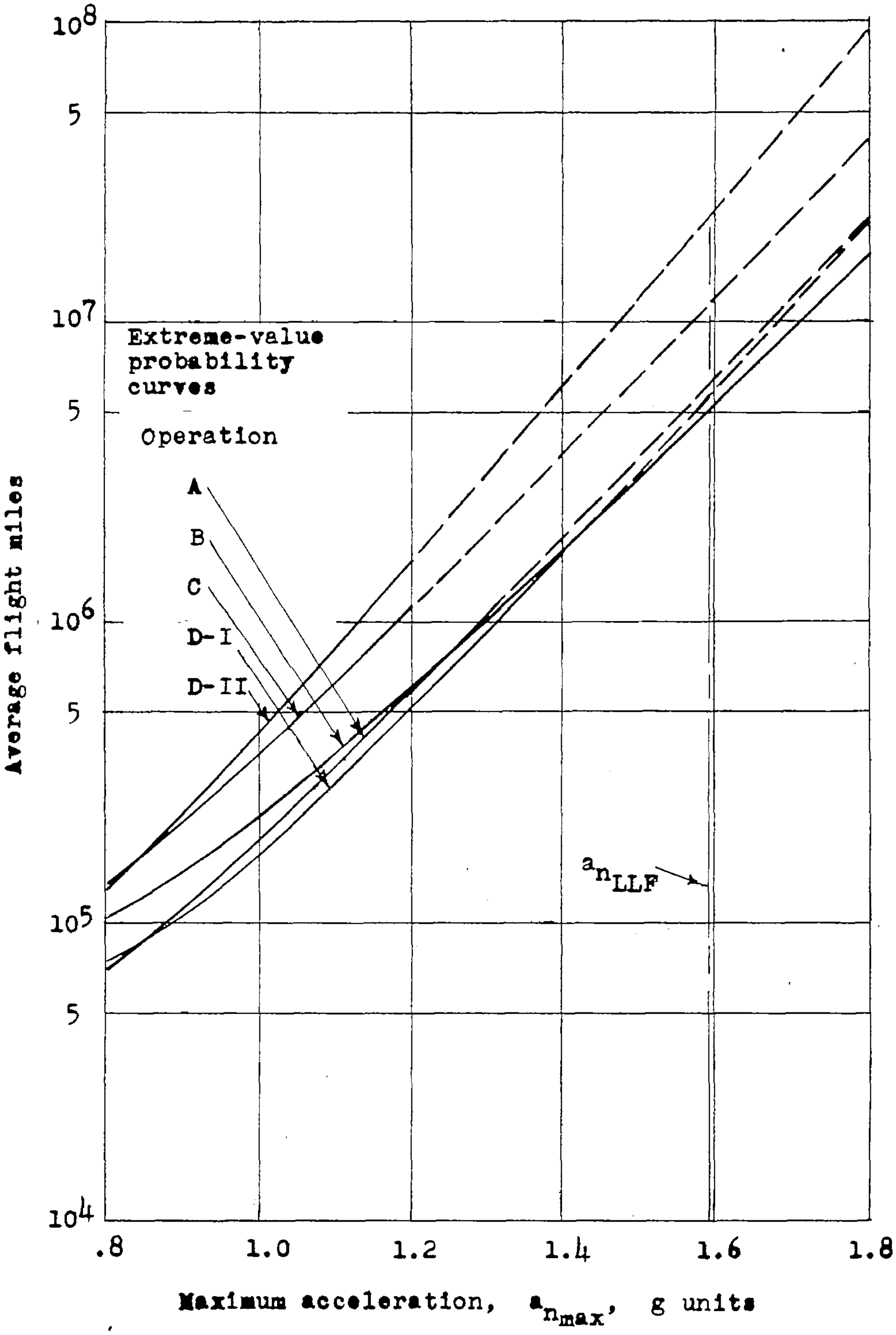

Figure 1.- Average flight miles for a maximum positive and negative acceleration to exceed a given value.

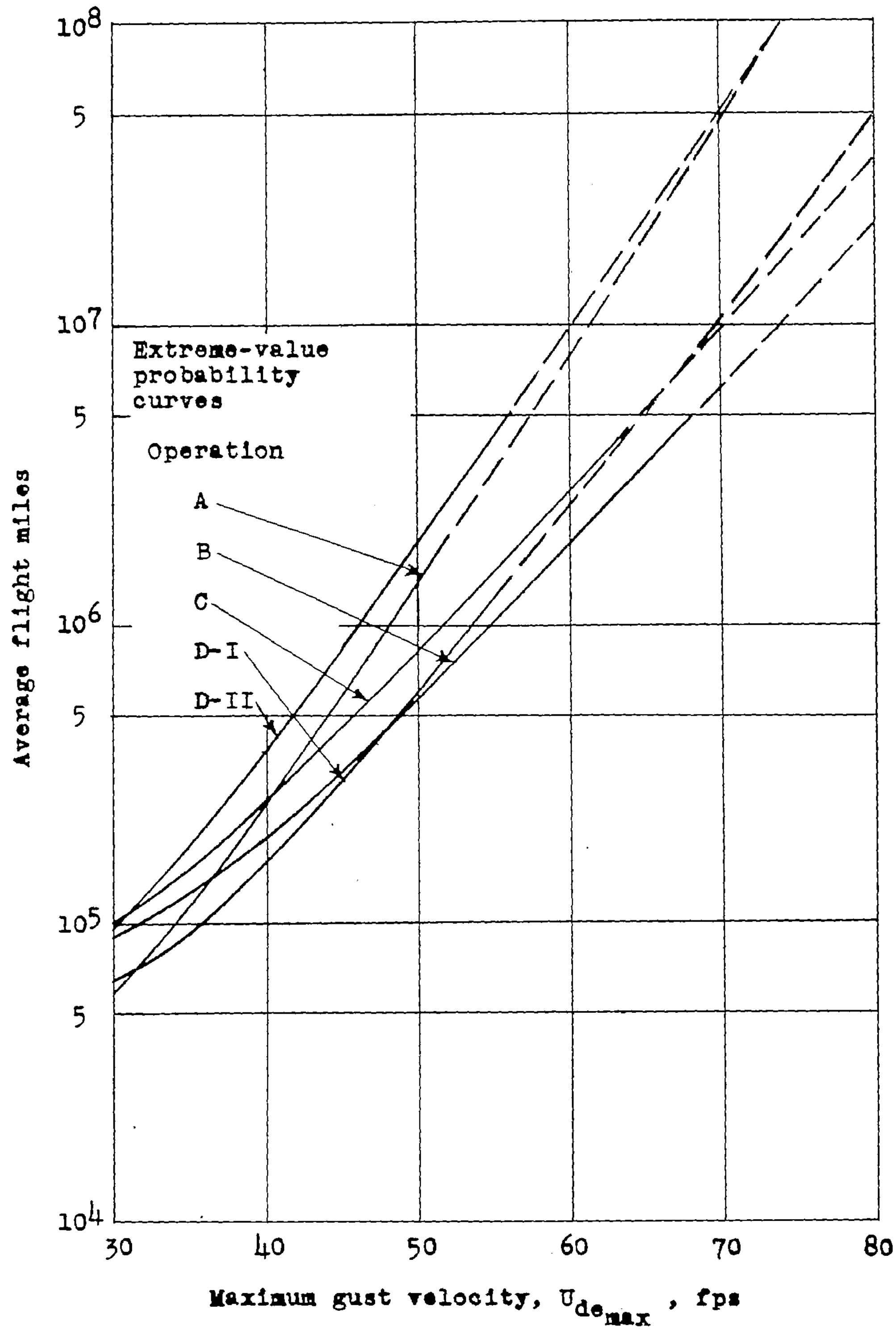

Figure 2.- Average flight miles for a maximum positive and negative derived gust velocity to exceed a given value.

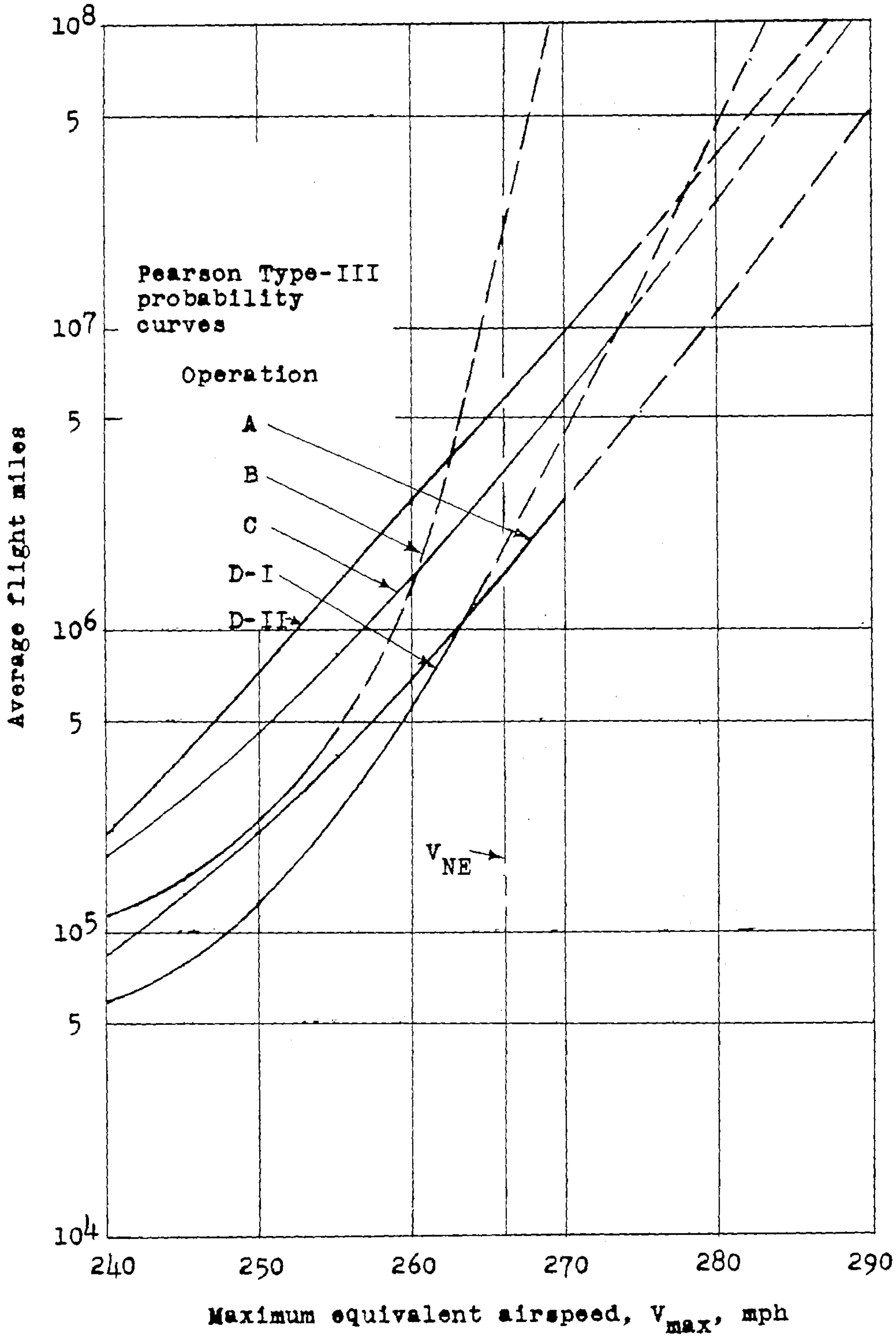

Figure 3.- Average flight miles for maximum equivalent airspeed to exceed a given value.

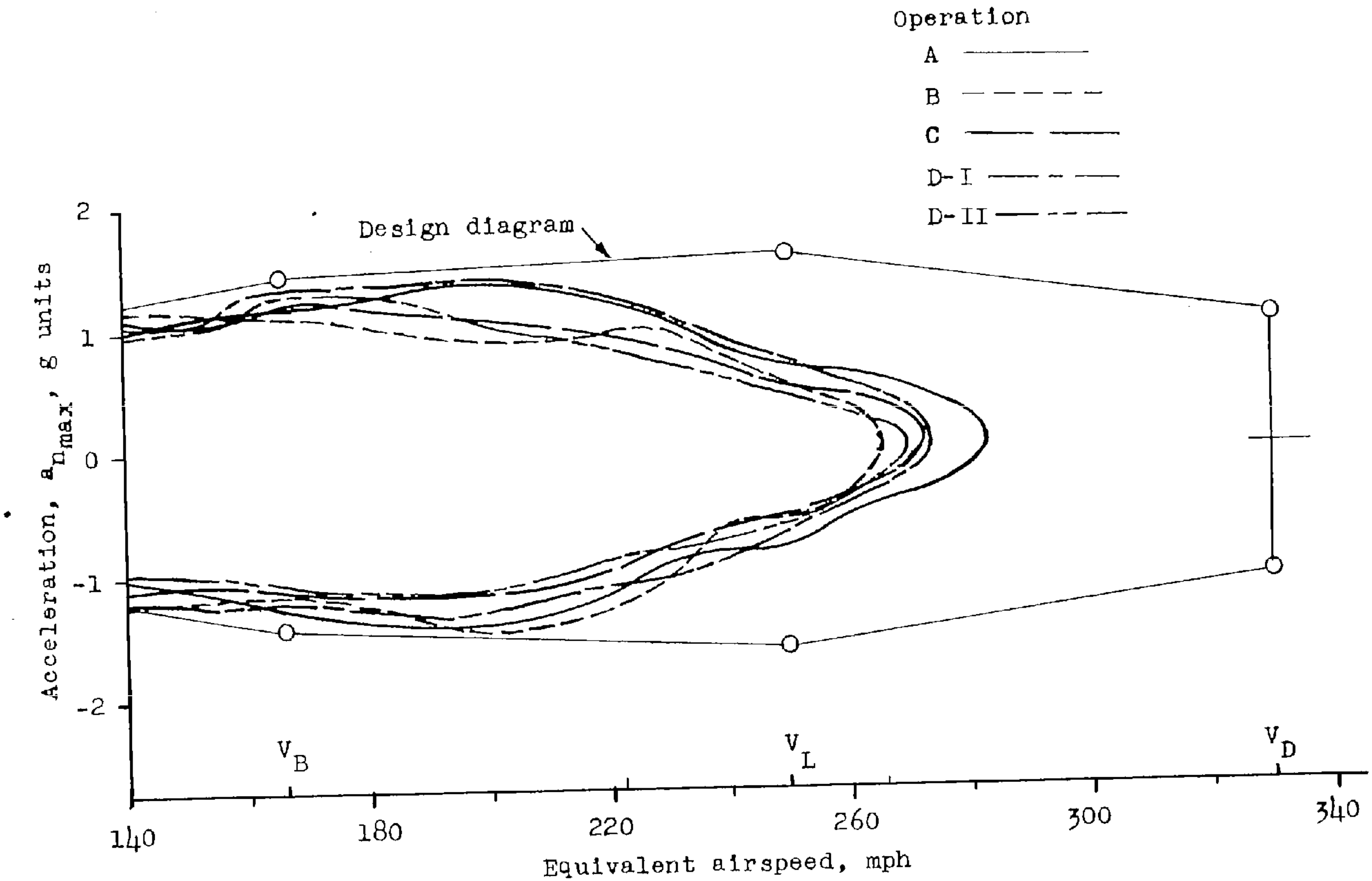

Figure 4.- Calculated gust-load envelopes for 10^7 flight miles of operations of the four-engine transport airplane on each of five different routes and a design gust-load diagram.

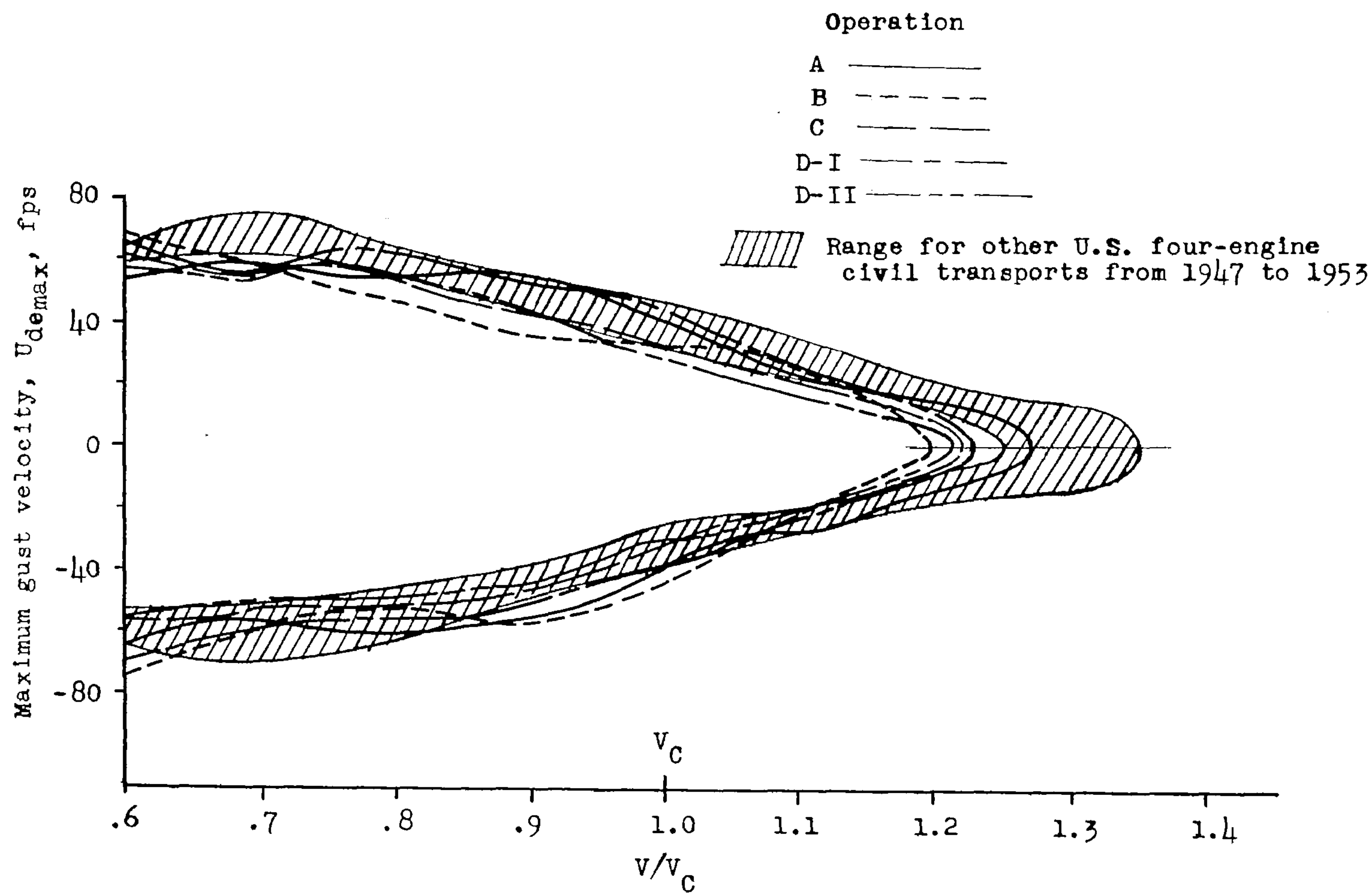

Figure 5.- Calculated gust-velocity envelopes for 10^7 flight miles of operations of the four-engine civil transport airplane on each of five different routes and the range for other United States civil-transport operations from references 2 and 3.